On Tevatron Lifetimes,

Beams and Luminosity

Paul Lebrun

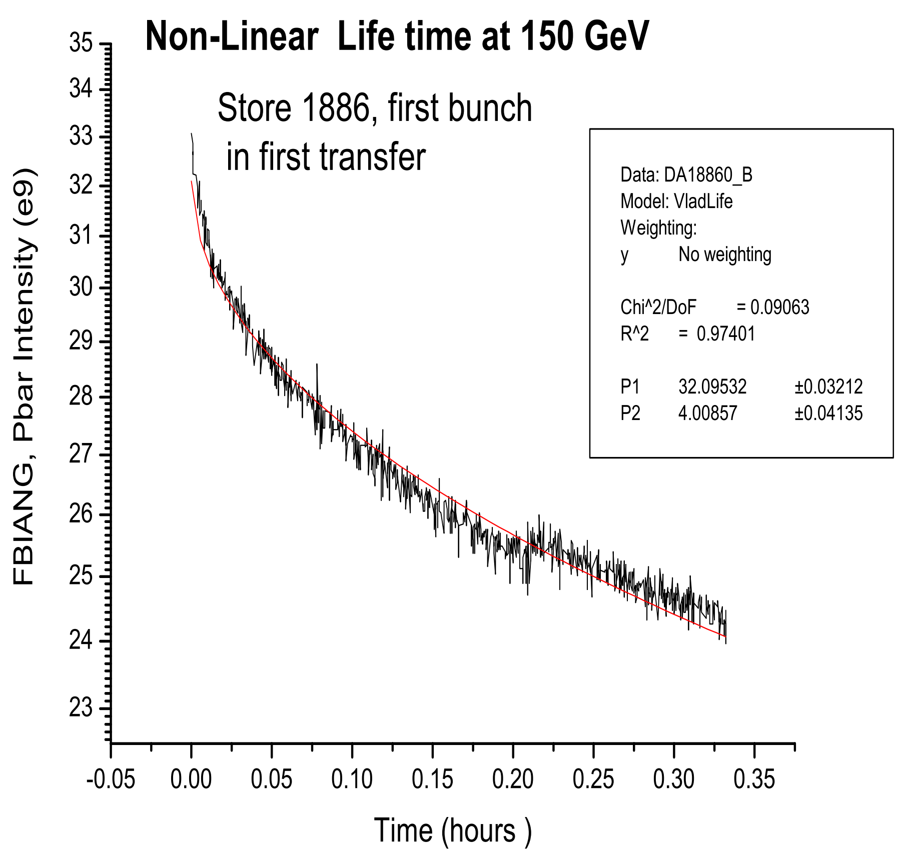
Fermilab

November 7 2002

Tevatron Lifetimes…

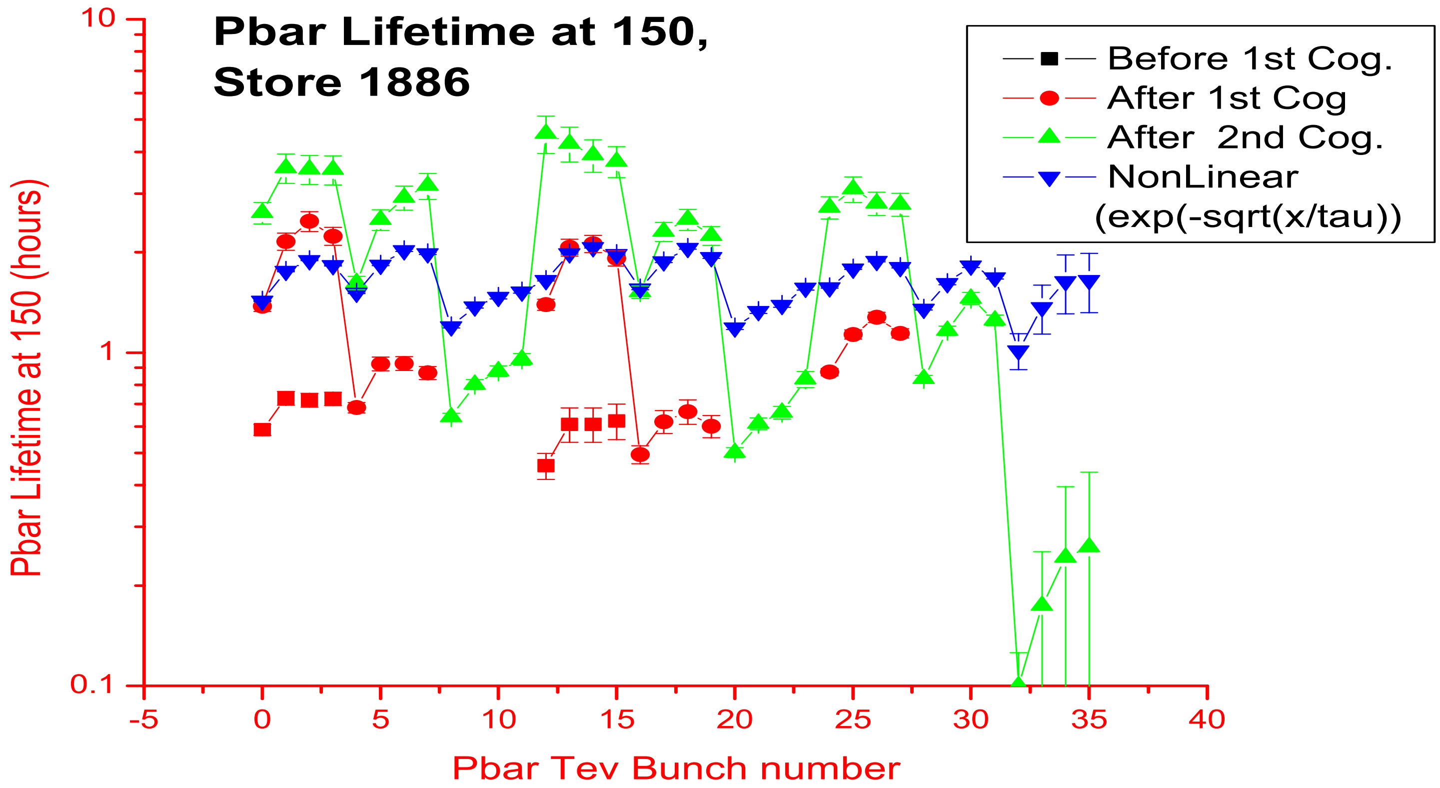
– Easy to calibrate! Not always easy to interpret!
– Outline
  - Pbar at 150 : time dependent !
  - Proton at 150, on the Helix..
  - Luminosity : 5 non-equal contributions.. More than one story.. We must watch the emittance growth!
– *Note: many of these slides have been shown at recent Tevatron Dept. meetings.. My apologies if you have seen them already..*

Pbar at 150: Non-linear lifetime, I~ e $^{-\mathrm{sqrt}(t/\tau)}$

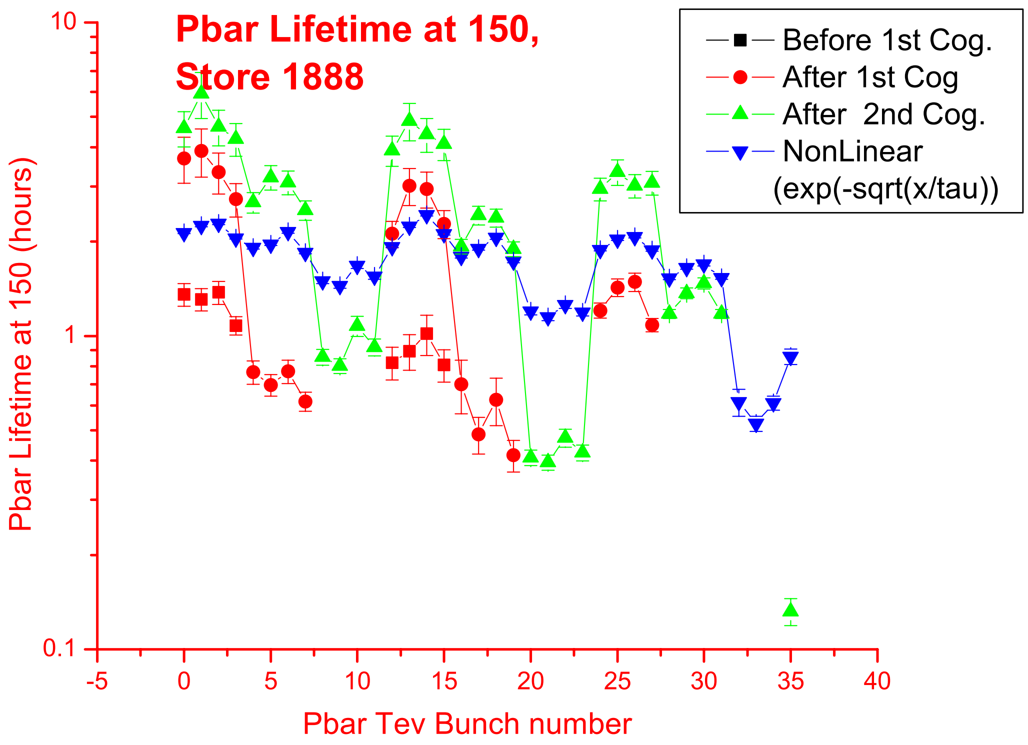


- Note the logarithm scale. Despite the non-linearity, such fits are surprisingly good. This bunch/store is not exceptional.
- Yet, the physics justification for such a formulas eludes me..
- One instrumentation caveat: we are still sensitive to the jump in FBI calibration at cogging time (around 21 min. after beginning of injection).

This Non-Linear lifetime is an average of “early” and “late” lifetime:

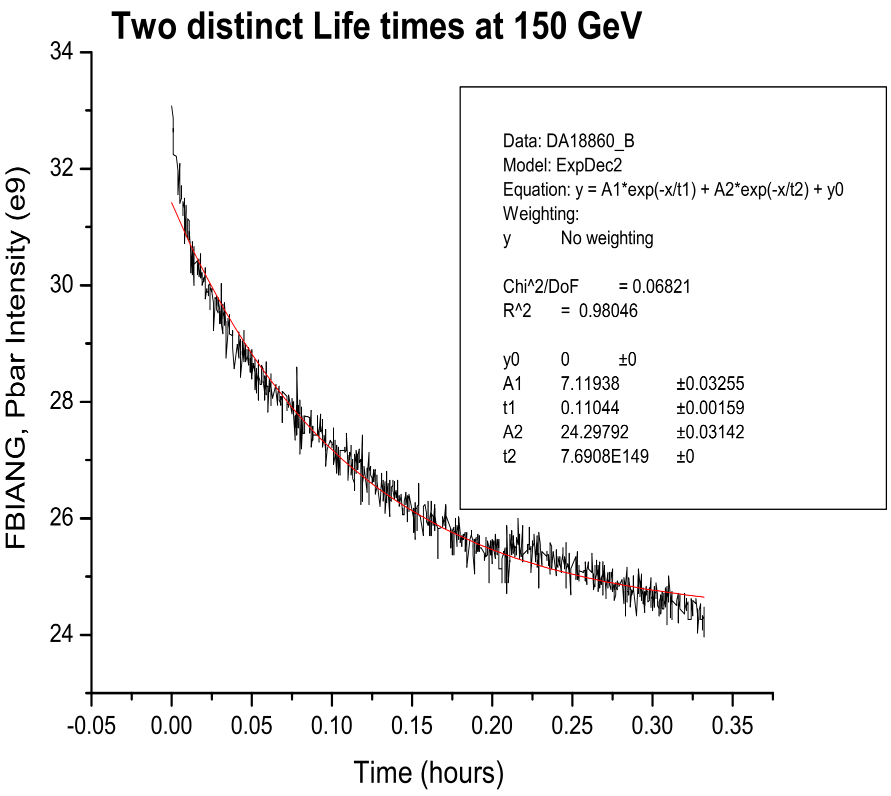


An other store..



Store 1888 was low Luminosity, low pbar Intensity, due to MI BLT tuning problem. Presumably, the emittance was larger. Yet, the lifetime is good..

Non-Linear lifetime, or multiple lifetimes?



- It dos not fit as well as the previous law, at short time! It truly is “time dependent lifetime”.
- Reasoning: (V. Shiltsev)

Beam-Beam @ Injection (cont'd)

V. Shiltsev

Combining

$$(dN/dt)/N = -(\varepsilon_0/\varepsilon)^{\alpha}/\tau_1$$

where $\alpha = 1 \div 1.5$*, and*

$$N \approx N_0 e^{-\sqrt{t/\tau_2}}$$

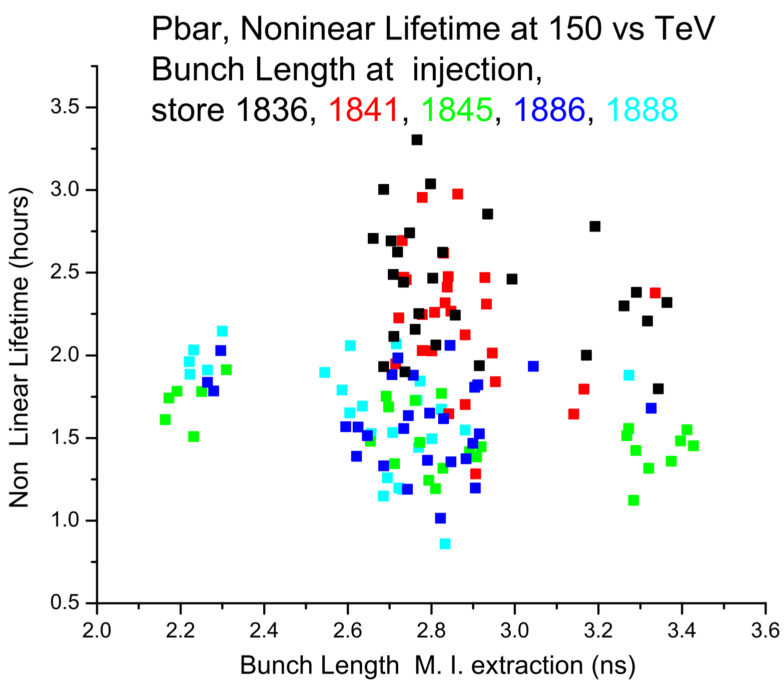
one gets

$$\varepsilon \propto (t/\tau_{\varepsilon})^{-\beta}$$

where $\beta = 1/(2\alpha) = 1/2 \div 1/3$*, and* $\tau_{\epsilon} = \tau_1^2/(4\tau_2)$*,*

i.e., we have shaving on aperture or "soft collimator"

Non- Linear Lifetime vs bunch length, ε, ?

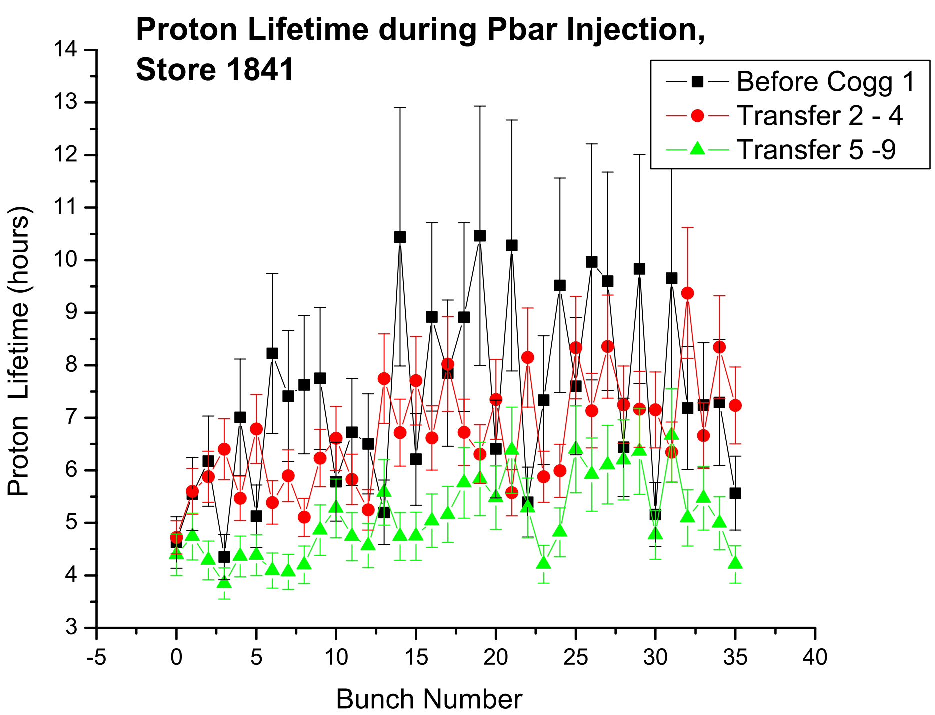


Does this non-linear linear lifetime (or "τ_1") depends on the emittance, or other factor? It should, however, we need better accuracy at determine the emittances (both longitudinal and transverse play a role). A first look at the TeV SBD, MI SBD and Flying wire data shows no convincing correlation. Or at least, not yet…

More studies..

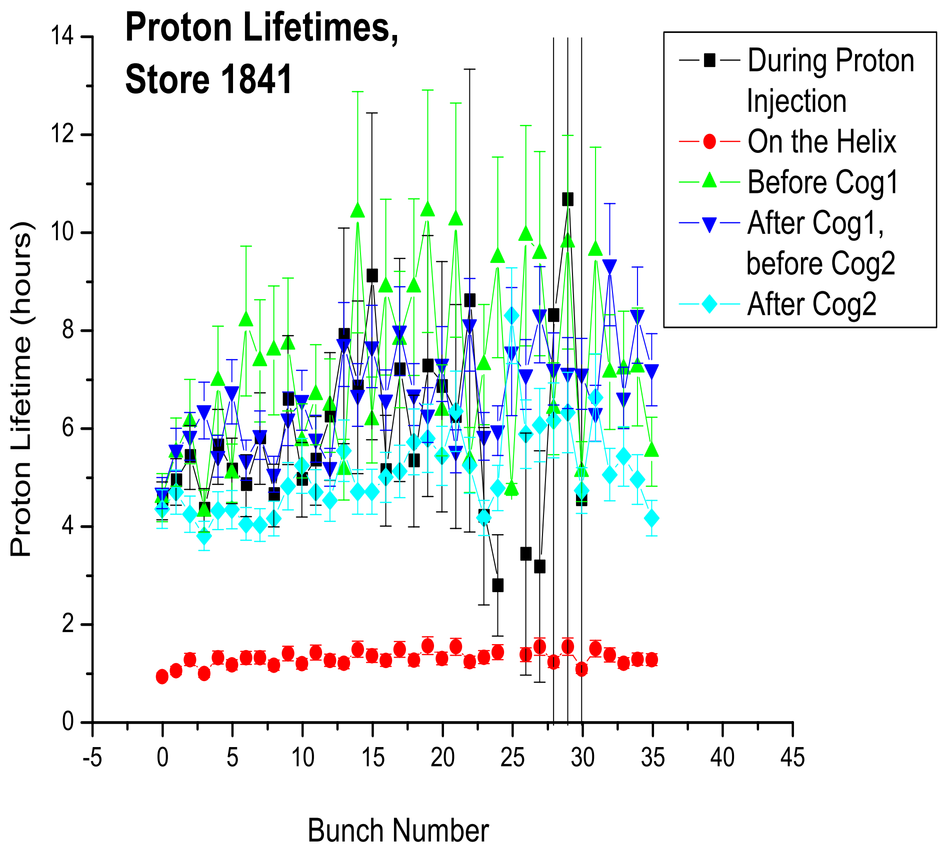
1. Correlation between transverse emittance at injection (in TeV) and lifetime. We need first to "stabilize" ("jumping" up and down of the emittance, measurement after measurement..) and re-calibrate the FWs before one can use the data..
2. If this model is correct, we should see a change in the emittance, for instance, the TeV Pbar bunch length is likely to change ($\alpha\beta \sim -0.5$) Thus, Study the SBD data (pbar bunch length) vs time at injection (The SBD data comes every few seconds..)
3. Correlate the lifetime with injection errors (e.g. with BLT data), which presumably slightly modify the average transverse position of the bunch.

Proton Lifetime, from FBIPNG / D44



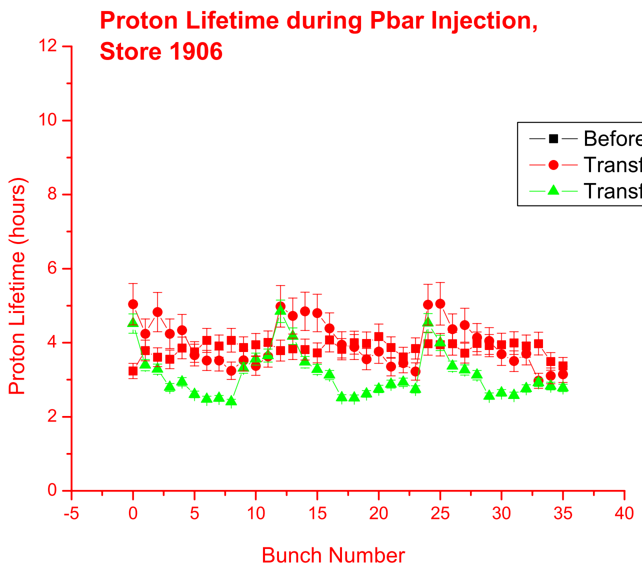
- The D44 "1Hz", "tentatively archived", has been used to measure the lifetime during pbar injection.
- The proton lifetime is not constant.
- For store 1841, the lifetime seems to decrease as we load more pbar. Do we see other systematic trends, store to store?

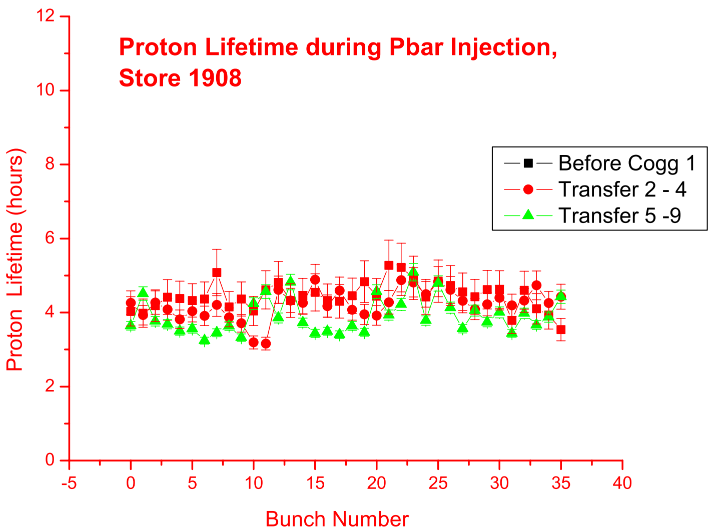
Proton Lifetime, before/during pbar injection.



- On the central orbit, while we inject proton the lifetime is quite long (~many hours).
- It suddenly drops to ~one hour when we move the beam on the helix.
- We stay there only for ~ 4 –10 min, typically, while the first pbar injection comes in.
- Then, the proton lifetime seems to climb back up to ~ 5 hours.
- ➔ Did we simply shave the beam against a hard aperture, or did the pbar had something with it?

Other stores..





The difference in lifetime between beginning and end of the pbar injection is, unfortunately, not reproducible. Note also that measuring a lifetime of about 4 hours with only a few minutes is not easy. Finally, for each pbar transfer, we of course have to fire the pbar kickers… Does this perturbs the proton beam?

Status…

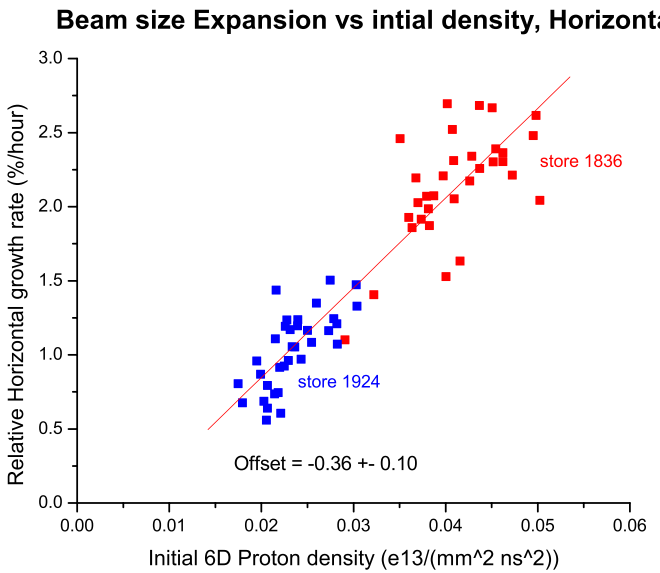
Sorting this out will probably require more studies:
starting with no pbar in TeV : "Lost Stack" study, 36x0 stores:

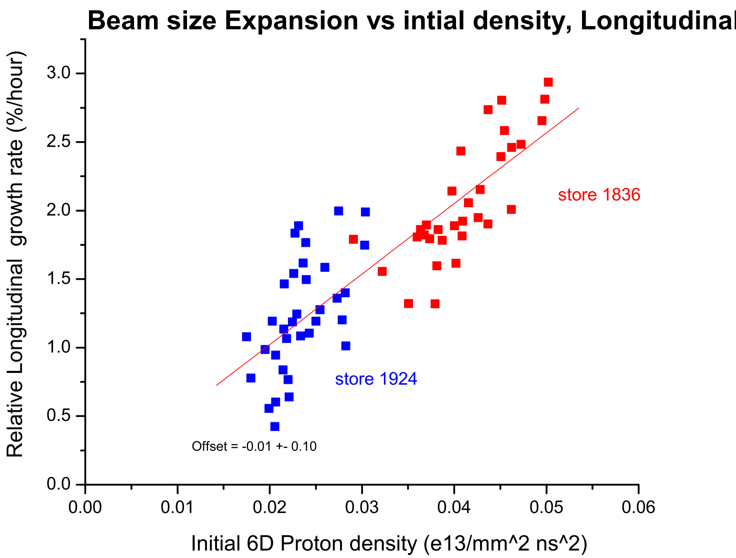
- Vary the time we stay on the helix. Measure the lifetime versus time. Do we also have a non-linear lifetime on the helix? Where do the losses occurs?
- Do "dry pbar" injection : fire the TeV pbar kicker as if we were taking beam, while the MI does not send beam to us. Measure the proton lifetime while this is going on. Locate where losses occur.

Next, "not too dedicated", study, 36x36 ..

Stay a bit longer on helix to let the proton shave itself off ?
(An $$$$$ study…)

Proton Emittance growth at 980





The initial 6D beam density comes from a direct measurement of the SyncLite spot sizes, the bunch length. The relative growth rate is also measured by the SBD and the SyncLite. Note that these two detector are completely independent from each others.. These growth rates have been measured at the beginning of the store, measurement duration of 2.5 hours. Bunch with an excess of 0.8 MHz loss rate have been excluded.

Luminosity Lifetime

– Over a short time period, the inverse of the luminosity lifetime can be approximated by:

$1/\lambda_l = 1/L\ dL/dt =$

$$1/\lambda_a + 1/\lambda_p + (2/\sigma_a\ (d\sigma_a/dt)\ /(1. + \varepsilon_p/\varepsilon_a)) +$$
$$(2/\sigma_p\ (d\sigma_p/dt)/(1. + \varepsilon_p/\varepsilon_a)) + 1/F\ dF/dt$$

where

λ_a, λ_p are the pbar and proton lifetimes,

Σ_a, σ_p are the beam width, average over both transverse planes,

ε_p, ε_a are the average over both transverse planes of the emittance.

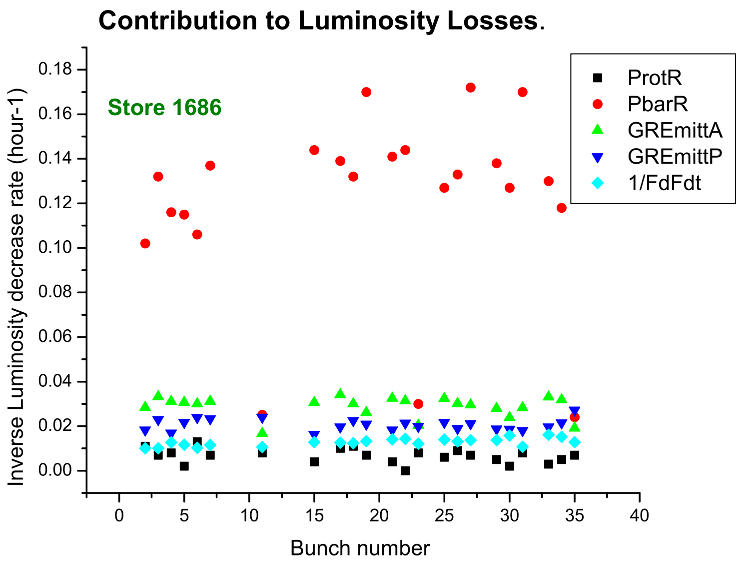
F is the hour glass factor, (M. Church phenomenological fit formula)

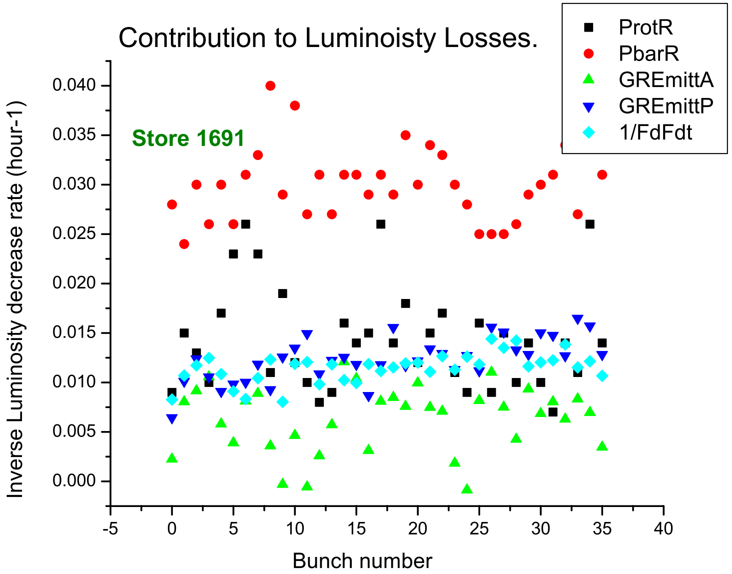
$F \sim 1.1117 - 0.6254 * \sigma_{0\beta} + 0.19358 * \sigma_{0\beta} * \sigma_{0\beta} - 0.02442 * \sigma_{0\beta}^3$,

$\sigma_{0\beta} = \sigma_t * c/\beta^*$, σ_t is the bunch length

Assumptions: round beam, about equal pbar and proton emittances.

Luminosity Lifetimes, term by term..

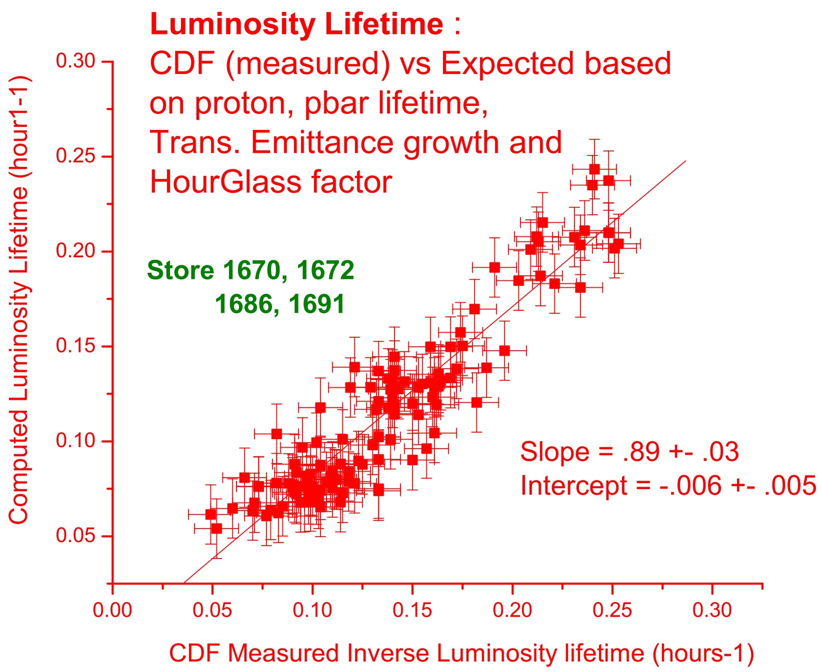




Store 1686 had an anomalously poor pbar lifetime, because the pbar emittance was too large. (We also had poor luminosity, ~15. e30) The ratio of collision rate over pbar disappearance rate was only 0.16 .

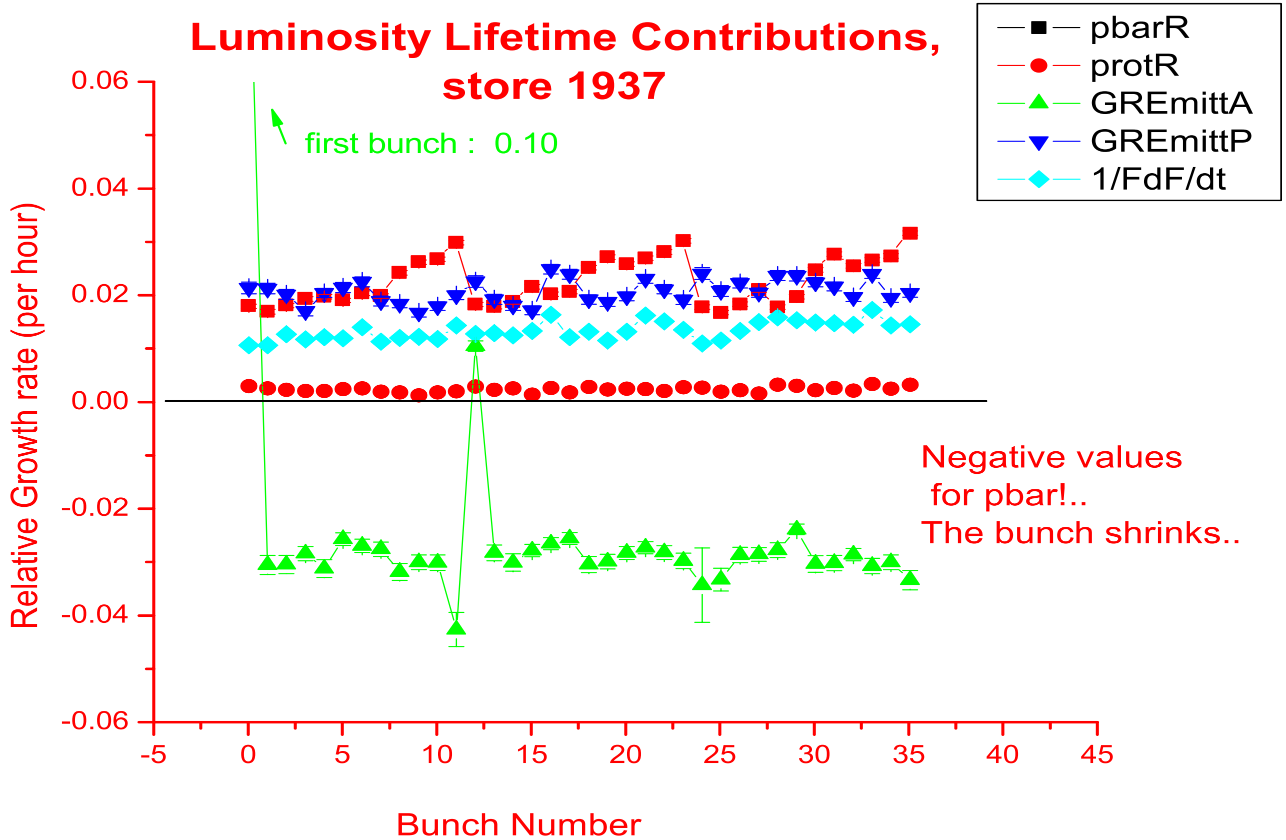
Store 1691 was more typical (L = 25. E30). About 66% of the antiproton are disappearing because of collision at B0 and D0 (assuming a cross section of 50 mB)

Comparison Measured vs Expected Lum. Lifetime

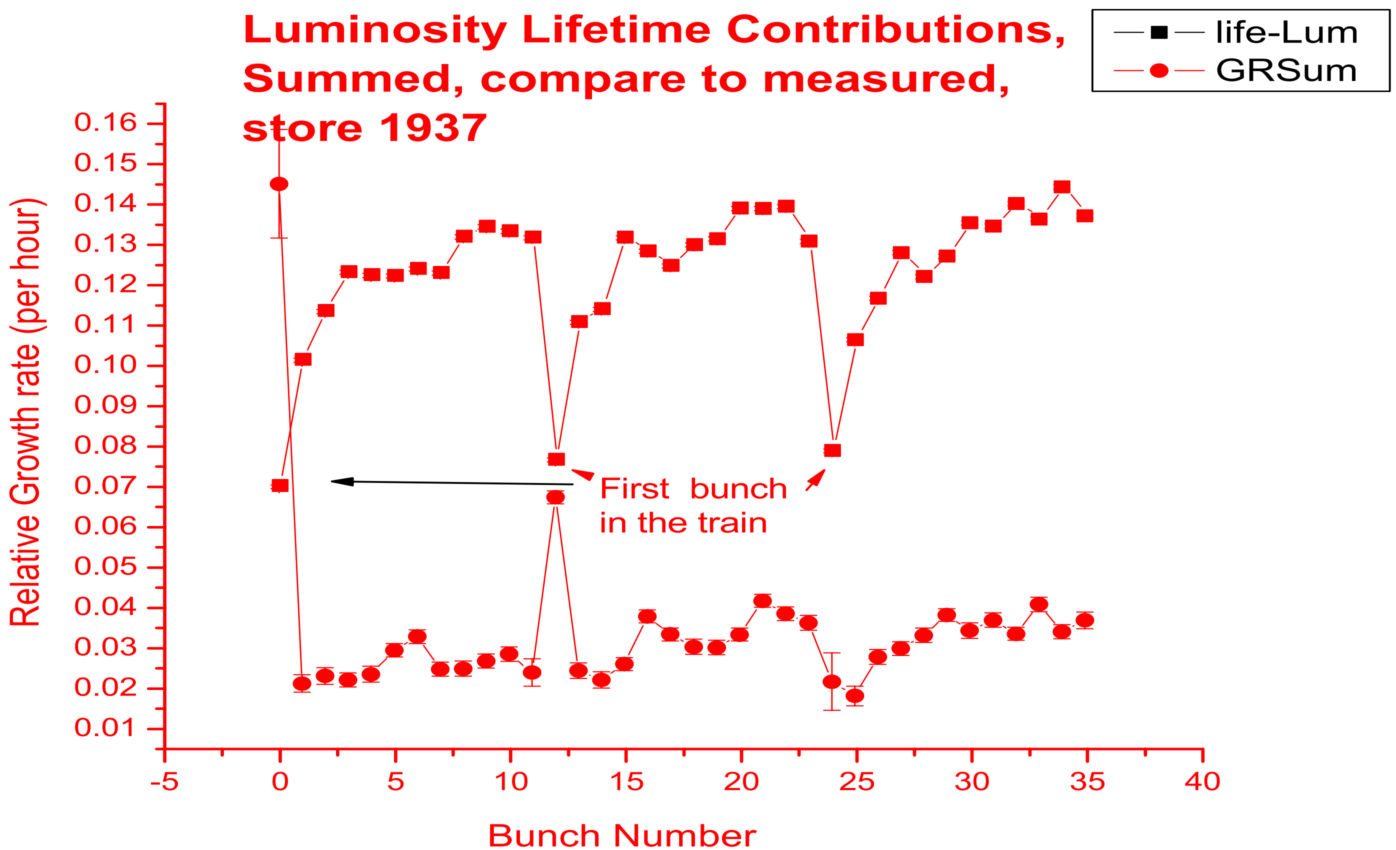


For these 4 stores, good agreement (~ 10 to 20%) is achieved.
Better agreement than absolute luminosity is reached, because a scaling and systematic uncertainties almost cancel. (And we can measure time with good accuracy).

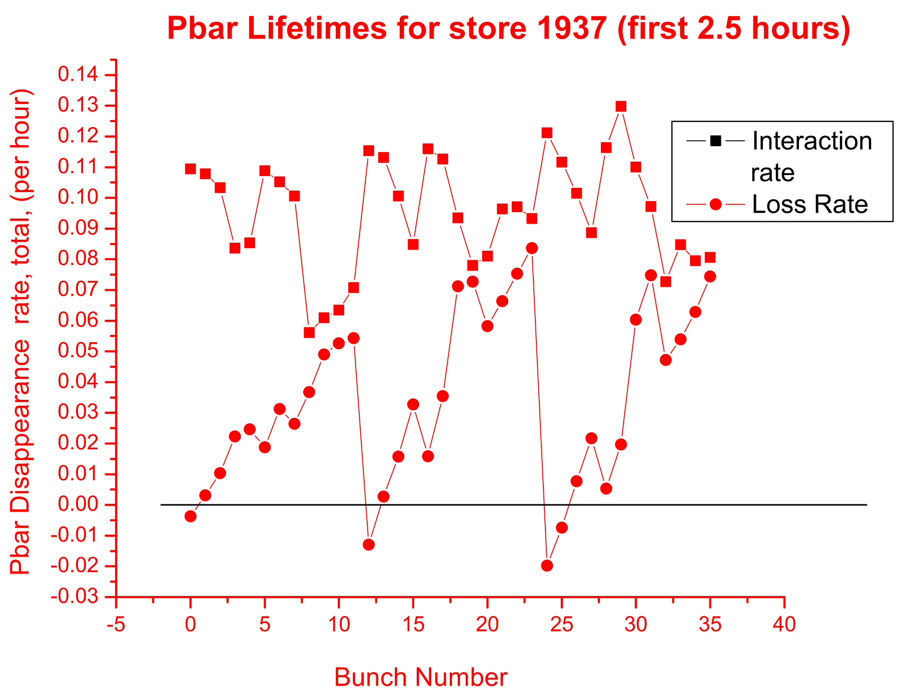
A recent store, # 1937, typical, (and not too good)



Summing Lifetime Contributions, Store 1937



Pbar Lifetime: Loss vs Luminosity , Store 1937



Very strong long range Beam-beam effects..

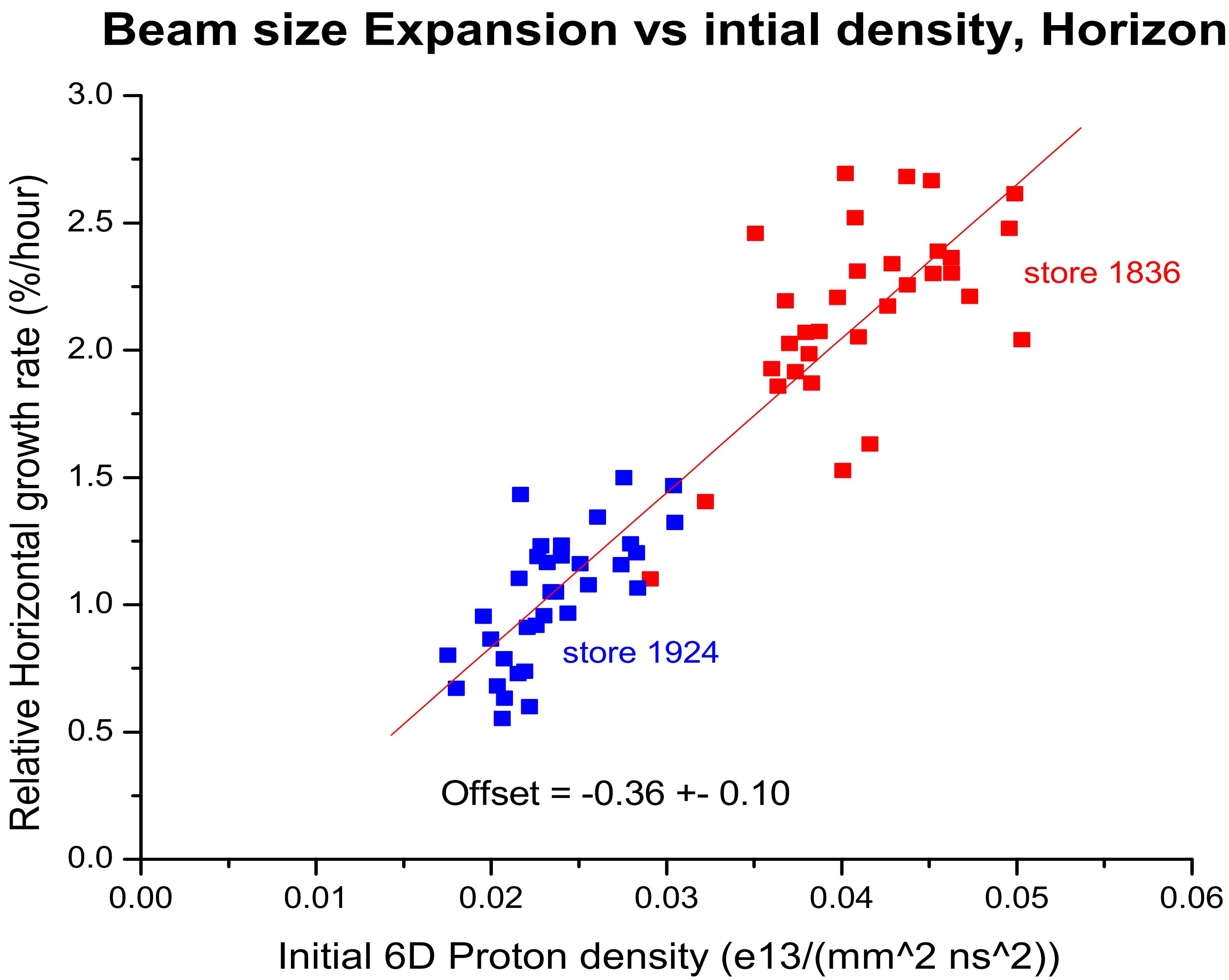
First bunch in train relatively Well behaved..

Last bunch in trains are Loosing pbars due to collision at B0, D0, (good), And elsewhere! (bad!)

Caveat: I have assume that for a given pbat bunch, the luminosity is identical at D0 and B0…

Proton Emittance Growth Rate at 980

- Increases with proton intensity
- Longitudinal and Horizontal growth are correlated (typically)..
- The relative growth rate is (often) proportional to 6D particle density
- This growth rate is time dependent.. It decreases vs time (consistent with the particle density dependence.
- For good store, 1/s ds/dt is ~ 2.5 % per hour (the emittance growth is double that amount).
- Currently, not a serious problem.. What if we succeed at reducing the proton bunch length and increase the number of particle per bunch. The RunIIa design value could raise the 6D density by ~ 3.6
- If so, this term will start to dominate the Luminosity lifetime.
- So, we probably should study it..


Beam size Expansion vs intial density, Horizontal
Relative Horizontal growth rate (%/hour)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Initial 6D Proton density (e13/(mm^2 ns^2))
store 1836
store 1924
Offset = -0.36 +- 0.10